Use of primary care data to predict those most vulnerable to cold weather: a case-crossover analysis

Tammes, Peter; Sartini, Claudio; Preston, Ian; Hay, Alastair D.; Lasserson, Daniel; Morris, Richard W.

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Research

Peter Tammes, Claudio Sartini, Ian Preston, Alastair D Hay, Daniel Lasserson and Richard W Morris

Use of primary care data to predict those most vulnerable to cold weather

a case-crossover analysis

Abstract

Background
The National Institute for Health and Care Excellence (NICE) recommends that GPs use routinely available data to identify patients most at risk of death and ill health from living in cold homes.

Aim
To investigate whether sociodemographic characteristics, clinical factors, and house energy efficiency characteristics could predict cold-related mortality.

Design and setting
A case-crossover analysis was conducted on 34 777 patients aged ≥65 years from the Clinical Practice Research Datalink who died between April 2012 and March 2014. The average temperature of date of death and 3 days previously were calculated from Met Office data. The average 3-day temperature for the 28th day before/after date of death were calculated, and comparisons were made between these temperatures and those experienced around the date of death.

Method
Conditional logistic regression was applied to estimate the odds ratio (OR) of death associated with temperature and interactions between temperature and sociodemographic characteristics, clinical factors, and house energy efficiency characteristics, expressed as relative odds ratios (RORs).

Results
Lower 3-day temperature was associated with higher risk of death (OR 1.011 per 1°C fall; 95% CI = 1.007 to 1.015; P<0.001). No modifying effects were observed for sociodemographic characteristics, clinical factors, and house energy efficiency characteristics. Analysis of winter deaths for causes typically associated with excess winter mortality (N = 7710) showed some evidence of a weaker effect of lower 3-day temperature for females (ROR 0.980 per 1°C, 95% CI = 0.959 to 1.002, P = 0.082), and a stronger effect for patients living in northern England (ROR 1.040 per 1°C, 95% CI = 1.013 to 1.066, P = 0.002).

Conclusion
It is unlikely that GPs can identify older patients at highest risk of cold-related death using routinely available data, and NICE may need to refine its guidance.

Keywords
case-crossover design; cold weather; England; longitudinal data; mortality; primary care.

INTRODUCTION

The phenomenon of excess winter deaths, whereby the death rate is higher during winter months than at other times of the year, is found worldwide, but appears particularly marked for the UK.[1–3] It is generally thought that there are two biological mechanisms — increased blood pressure and increased clotting — through which cold might exert its effect.[4] The dual environmental issues of cold housing and fuel poverty have been highlighted.[5] Wilkinson and associates found associations between excess winter mortality and the age of the property, and poor thermal efficiency ratings.[6] Though ecological studies in the UK found no relation of deprivation to increased mortality during cold weather, some evidence was found for age, sex, and medical (chronic) conditions.[7–11] In 2015, the National Institute for Health and Care Excellence (NICE) guideline on excess winter deaths[12] recommended that primary care team practitioners should help identify people at risk of ill health from living in a cold home, in collaboration with relevant local authority departments, using existing data and professional contacts. Assessing the heating needs of primary care patients once a year should be done during a home visit or through questioning during consultation.[13,14] This study aimed to assess whether primary care staff are able to identify people at risk during cold snaps, using a simple algorithm based on information on clinical factors, sociodemographic characteristics, living situation, and location provided in electronic patient records (EPR). As GP home visits are undertaken opportunistically rather than systematically, and cannot reliably identify all those at risk from poorly heated homes, house energy efficiency at lower super output area (LSOA) level was used as a marker of risk. The focus was on patients aged ≥65 years, as these patients are most at risk from temperature-related mortality.[8]

METHOD

Study design and setting

Data were obtained from the Clinical Practice Research Datalink (CPRD), which contains current data on 4.4 million anonymised patient records (6.9% of the UK population) and are nationally representative for age, sex, and ethnicity.[15] The patient's postcode is recorded at the general practice, and used to assign an LSOA of residence. The CPRD can be linked with Hospital Episode Statistics (HES) and Office for National Statistics (ONS) mortality data in England,[16] and patients in CPRD who could be linked by their NHS number to these data in England were investigated.

This study tested the association between

P Tammes, PhD, senior research associate; **AD Hay**, MD, FRCGP, DCH, professor of primary care; **RW Morris**, PhD, professor in medical statistics, Centre for Academic Primary Care, Bristol. **C Sartini**, MSc, research statistician, Department of Primary Care and Population Health, University College London, London. **I Preston**, BSc, head of household energy services, Centre for Sustainable Energy, Bristol. **D Lasserson**, MA, MD, FRCP Edin, MRCGP, professor of ambulatory care, Institute of Applied Health Research, College of Medical and Dental Sciences, University of Birmingham, Birmingham.

Address for correspondence

Peter Tammes, University of Bristol, Bristol Medical School, Population Health Sciences, Centre for Academic Primary Care (CAPC), Canynge Hall, 39 Whatley Road, Bristol, BS8 2PS, UK.

E-mail: p.tammes@bristol.ac.uk

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How this fits in

There is excess winter mortality in England and Wales, therefore the National Institute for Health and Care Excellence recommends that GPs use existing data to identify patients most at risk from living in a cold home. When analysing routine data from over 300 general practices on patients aged ≥65 years who died over a 2-year period, this study found that every 1°C drop in temperature was associated with a mortality increase of 1.1%. However, little evidence was found to show that vulnerable subgroups could be identified using routine data. It is unlikely that GPs can use medical records to identify older patients most at risk from cold weather.

periods of cold absolute temperatures over a short period and risk of death by making use of a case-crossover design as cold temperature was expected to be intermittent, and to have an immediate and transient effect.[17] In a case-crossover design each participant serves as their own control, which eliminates potential influence of between-participant variation. Within this study two control times are supplied by each of the cases themselves, using symmetric bidirectional sampling, that is, past and future controls, to adjust for possible calendar time trends.[18] There was a particular aim to identify subgroups for whom the relationship between temperature and death was strongest, because these subgroups would contain those most vulnerable.

Table 1. Distribution of temperature measures around dates of death, and 28 days before and after deaths

	Temperature, absolute daily mean temperature in °C, mean (median, interquartile range)	
Time of measure	**Whole study period**	**Wintertime within study period[a]**
3-days lag period, 28th day before death	9.623 (8.775, 6.000–13.800)	5.492 (5.900, 4.100–7.325)
3-days lag period, date of death	9.543 (8.700, 5.875–13.675)	5.111 (5.450, 3.325–7.125)
3-days lag period, 28th day after death	9.669 (9.125, 5.950–13.700)	5.738 (5.875, 3.425–8.075)
13-days lag period, 28th day before death	9.630 (8.779, 6.029–13.736)	5.673 (5.986, 4.443–7.064)
13-days lag period, date of death	9.552 (8.700, 5.982–13.614)	5.168 (5.457, 3.586–6.707)
13-days lag period, 28th day after death	9.665 (9.143, 6.036–13.664)	5.649 (5.879, 3.564–7.457)

[a]*Months December to March between 1 April 2012 and 31 March 2014.*

Measuring temperature and lag periods

Daily temperature data from the Met Office was used. It was ensured that data were collated between weather stations within each of the 10 English Strategic Health Authorities (SHAs), so that, for any given day, only one value of the relevant weather variable was assigned to every practice and patient within each authority. The station with the overall highest correlation with all other stations within the same SHA was chosen. These temperature data were used to calculate the average daily temperature over a lag period. There is no agreement about the lag period of mortality following cold periods, ranging from a few days to 23 days, though a recent systematic review concluded that lags of up to 9 days in exposure to cold temperature intervals were substantially associated with all-cause mortality.[19,20] In this study, the focus was on the impact of the temperature for the date of death and 3 days previously (3-days lag period), assuming that a more immediate impact of temperature is bigger and therefore it may allow for quicker interventions by GPs. This 3-day lag period for both temperature measures for the 28th day before and the 28th day after the date of death (control dates). The 28th day was chosen to adjust for the longer-term, seasonal-related effects of temperature so that the effect of the 3-day mean represents a short-term effect only. In a sensitivity analysis the focus was on the impact of the temperature based on a 13-days lag period, as suggested by Wilkinson *et al*.[7] The mean and median of the temperature measures are presented in Table 1, demonstrating that temperatures were lower on dates of death than on control dates.

Effect modifiers

This study investigated whether any of the following modified the effect of 3-day temperature: age (categorised as 65–74, 75–84, or ≥85 years), living in an institution (coded according to whether the patient's family ID number appeared more than twice in the study CPRD patient file) — the prevalence of this rises with age,[21] quintiles of the 2015 English Indices of Multiple Deprivation (IMD2015) score, calculated at LSOA residence level, house energy efficiency at LSOA level (using percentage of properties at LSOA level with ratings of E, F, or G, indicating efficiency lower than 55%), urbanicity (categorised as conurbation, urban, or rural), and north/south of England location (south defined as located in the South West, South Central, London, East of England, or South East of England SHAs). In

Table 2. Characteristics of 34 752 patients who died and used in case-crossover analysis

Patient characteristic	Patients who died between 1 April 2012 and 31 March 2014, *N* (%)	Patients who died in winter months (December to March),[a] *N* (%)	Patients who died in other seasons and/or due to other diseases, *N* (%)
Sex			
Male	16 043 (46.2)	3337 (43.3)	12 706 (47.0)
Female	18 709 (53.8)	4373 (56.7)	14 336 (53.0)
Age at death, years			
65–74	6442 (18.5)	920 (11.9)	5522 (20.4)
75–84	11 516 (33.1)	2400 (31.1)	9116 (33.7)
≥85	16 794 (48.3)	4390 (57.0)	12 404 (45.9)
Living situation			
Community	31 671 (91.1)	6833 (88.6)	24 838 (91.9)
Institution	3081 (8.9)	877 (11.4)	2204 (8.1)
Location			
Urban conurbation	10 583 (30.5)	2339 (30.3)	8244 (30.5)
Cities and towns	20 198 (58.1)	4496 (58.3)	15 702 (58.1)
Rural	3971 (11.4)	875 (11.4)	3096 (11.4)
Deprivation level (IMD)			
Q1 (least deprived)	7217 (20.8)	1555 (20.2)	5662 (20.9)
Q2	8051 (23.2)	1756 (22.8)	6285 (23.3)
Q3	7473 (21.5)	1704 (22.1)	5769 (21.3)
Q4	6362 (18.3)	1435 (18.6)	4927 (18.2)
Q5 (most deprived)	5649 (16.3)	1260 (16.3)	4389 (16.2)
House energy efficiency			
Q1 (lowest inefficiency)	5206 (15.0)	1173 (15.2)	4033 (14.9)
Q2	8115 (23.4)	1813 (23.5)	6302 (23.3)
Q3	8216 (23.6)	1821 (23.6)	6395 (23.7)
Q4	7845 (22.6)	1731 (22.5)	6114 (22.6)
Q5 (highest inefficiency)	5370 (15.5)	1172 (15.2)	4198 (15.5)
Emergency hospital admission within 2 years of death			
No	6081 (17.5)	1575 (20.4)	4506 (16.7)
Yes	28 671 (82.5)	6135 (79.6)	22 536 (83.3)
Chronic condition(s)[b]			
No	21 259 (61.2)	5601 (72.7)	15 658 (57.9)
Yes	13 493 (38.8)	2109 (27.3)	11 384 (42.1)
Region			
South	11 593 (33.4)	2593 (33.6)	9000 (33.3)
North	23 159 (66.6)	5117 (66.4)	18 042 (66.7)
Total	**34 752 (100.0)**	**7710 (100.0)**	**27 042 (100.0)**

[a]Patients who died in winter months (December to March) between 1 April 2012 and 31 March 2014 due to diseases of the circulatory system, respiratory system, nervous system, or mental and behavioural disorders. [b]Diagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. COPD = chronic obstructive pulmonary disease.

addition, from the CPRD immunisation file patients who had undergone their winter flu vaccination were identified (Appendix 1).

Data from linked Hospital Episode Statistics determined whether an emergency hospital admission occurred 2 years before death to indicate previous health status. This study also determined who was diagnosed with one or more of the following seven chronic conditions: chronic renal disease,[22] cancer,[23] asthma,[22] stroke,[24] coronary heart disease,[24] diabetes,[24] and chronic obstructive pulmonary disease (COPD).[25] Published clinical code lists were used, as collected in the Manchester Clinical Codes repository.[26]

Statistical methods

Conditional logistic regression models may be applied to these case-crossover data to estimate the odds of exposure to the temperature on the date of death, relative to the odds of exposure to the temperature on the 'control' dates. This is equivalent to the odds of death given the temperature on the date of death, compared with that on the control dates. This study thus estimated not only the odds ratio (OR) of

Table 3. Main effects from a univariable analysis of relationship between 1°C fall in average temperature in °C (3-days lag period)[a] and death (odds ratios [*P*-value]), using 28th day before and after date of death as control days

	3-days lag			13-days lag		
	OR	**95% CI**	***P***	**OR**	**95% CI**	***P***
Overall	1.011	1.007 to 1.015	<0.001	1.013	1.008 to 1.018	<0.001
Winter time[b]	1.079	1.067 to 1.091	<0.001	1.138	1.121 to 1.155	<0.001

[a]Based on temperatures of date of death and 3 days previous (case day), and 28th day before date of death and 3 days previous and 28th day after date of death and 3 days previous (control days). [b]Those who died in the months December to March of diseases of the circulatory system, respiratory system, nervous system, or mental and behavioural disorders.

death associated with 3-day temperature but also interactions between temperature and sociodemographic characteristics, clinical factors, and house energy efficiency characteristics; these interactions were expressed as relative odds ratios (RORs). Because certain causes of death are documented as being responsible for the vast majority of excess winter deaths,[27] the second analysis focused on patients who died in winter of diseases of the circulatory system, respiratory system, nervous system, and mental and behavioural disorders, using the International Classification of Diseases (ICD)-10 classification. Among the 34 777 patients in our study those conditions showed higher death rates in winter than in other seasons (Appendix 2).

RESULTS

There were 537 623 patients within 322 English general practices who were eligible in the CPRD source population for linkage to HES and ONS mortality data and aged ≥65 years during at least a part of the observation period 1 April 2012 to 31 March 2014. Linkage of ONS mortality data to the study population revealed 34 777 patients aged >65 years who died between 1 April 2012 and 31 March 2014: 6445 (18.5%) died aged 65–74 years, 11 525 (33.1%) aged 75–84 years, and 16 807 (48.3%) aged ≥85 years. This was similar to percentages for all deaths >65 years of age in England and Wales in 2012–2014, being 19.3%, 34.7%, and 46.0% for the three age groups. After excluding 25 individuals with missing data on deprivation, the total number of deaths used in the analyses was 34 752, of whom 7710 died during winter months of causes most related to winter mortality (Appendix 2). These patients are described in Table 2; χ^2 tests show that those who died in winter due to those causes were more likely to be female, aged >85 years, live in institutions, and less likely to have experienced an emergency hospital admission 2 years prior to death or to suffer chronic conditions.

Lower 3-day temperature was associated with higher risk of death (OR 1.011 per 1°C; 95% CI = 1.007 to 1.015; *P*<0.001) (Table 3). No interactions were found between temperature measures and age, sex, living in an institution, living in urban/rural areas, living in northern or southern part of England, deprivation level, or house energy efficiency in either unadjusted analyses — containing only the absolute temperature and their interaction with a specific covariate — or adjusted analyses, which allowed for interactions between temperature and all covariates simultaneously (Table 4).

The authors further examined the effect for winter flu vaccination undertaken yearly between September and October, and found that 57% of the patients in this analysis had taken their flu vaccination. Flu vaccination made no impact on protection from cold temperature.

When using mean temperature over 13 days prior to the date of death (or equivalent control dates), a similar association was found for absolute temperature (Table 3: OR 1.013 per 1°C; 95% CI = 1.008 to 1.018; *P* = <0.001). Nearly all interactions between temperature measures and sociodemographic measures were non-significant in both unadjusted and adjusted analysis (Appendix 3). Both the unadjusted and the adjusted analysis showed evidence for a stronger effect of low 13-day temperature for patients living in the northern part of England (unadjusted ROR northern England: 1.009 per 1°C, 95% CI = 0.999 to 1.019; *P* = 0.084; adjusted ROR 1.010, 95% CI = 0.999 to 1.020, *P* = 0.078, see Appendix 3).

When focusing on patients who died in winter of diseases related to the circulatory system, respiratory system, nervous system, or mental and behavioural disorders, bivariable analyses showed lower 3-day temperature was associated with higher risk of death (OR 1.079 per 1°C; 95% CI = 1.067 to 1.091; *P*<0.001) (Table 3). There was little evidence of interactions between temperature measures and sociodemographic variables (Table 5), although there was weak evidence for a reduced effect of lower temperature for female patients (adjusted ROR per 1°C for females: 0.980, 95% CI = 0.959 to 1.002, *P* = 0.082), suggesting more impact of 3-day temperature for male patients. Furthermore, there was some evidence of a stronger effect of lower absolute temperatures for patients living in northern

Table 4. Unadjusted and adjusted interaction effects with average temperature fall per 1°C (3-days lag period[a] on death among patients aged ≥65 who died in the financial years 2012/2013 to 2013/2014 (*N* = 34 752 deaths)

	Unadjusted				Adjusted		
	OR[b]	ROR[c]	95% CI	*P*-value	ROR	95% CI	*P*-value
Temperature*sex (ref=male)	1.012						
Female	1.009	0.997	0.989 to 1.005	0.474	0.996	0.996 to 1.005	0.420
Temperature*age died (ref=65–74), years	1.011						
75–84	1.010	0.999	0.987 to 1.011	0.877	1.000	0.987 to 1.012	0.937
≥85	1.011	1.001	0.989 to 1.012	0.901	1.002	0.991 to 1.014	0.696
Temperature*community (ref) or institution	1.012						
Institution	1.003	0.992	0.978 to 1.006	0.263	0.990	0.976 to 1.006	0.220
Temperature*urban (ref=urban conurbation)	1.013						
Cities and towns	1.010	0.997	0.988 to 1.006	0.531	1.000	0.990 to 1.010	0.990
Rural	1.009	0.996	0.982 to 1.011	0.637	0.998	0.982 to 1.014	0.791
Temperature*IMD (ref=Q1)	1.008						
Q2	1.011	1.003	0.991 to 1.016	0.586	1.003	0.991 to 1.015	0.614
Q3	1.010	1.002	0.989 to 1.015	0.738	1.002	0.989 to 1.015	0.753
Q4	1.011	1.003	0.990 to 1.017	0.616	1.003	0.990 to 1.017	0.637
Q5 (most deprived)	1.015	1.007	0.993 to 1.020	0.346	1.005	0.991 to 1.020	0.478
Temperature*house energy efficiency (ref=Q1)	1.009						
Q2	1.013	1.003	0.989 to 1.017	0.659	1.004	0.990 to 1.018	0.553
Q3	1.009	1.000	0.986 to 1.014	0.988	1.001	0.987 to 1.015	0.856
Q4	1.009	0.999	0.985 to 1.013	0.914	1.001	0.987 to 1.016	0.857
Q5 (highest inefficiency)	1.014	1.005	0.989 to 1.020	0.550	1.007	0.991 to 1.025	0.374
Temperature*emergency admission (ref=no)	1.017						
Yes	1.010	0.993	0.982 to 1.004	0.220	0.992	0.981 to 1.003	0.164
Temperature*chronic conditions[d] (ref=no)	1.012						
Yes	1.009	0.997	0.988 to 1.005	0.467	0.997	0.988 to 1.005	0.468
Temperature*north/south divide (ref=south)	1.008						
North	1.016	1.008	0.999 to 1.017	0.100	1.008	0.998 to 1.017	0.118

[a]Based on temperatures of date of death and 3 days previous (case day), and 28th day before date of death and 3 days previous and 28th day after date of death and 3 days previous (control days). [b]Odds ratio per 1°C fall in temperature. [c]Relative odds ratio to indicate modifying effect of factor to temperature, for example, for sex: odds ratio for females divided by odds ratio for males: ROR female = 1.009/1.012 = 0.997. [d]Diagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. = interaction. COPD = chronic obstructive pulmonary disease. OR = odds ratio. ref = reference. ROR = relative odds ratio.*

parts of England in the unadjusted analysis (ROR per 1°C for north England: 1.037, 95% CI = 1.013 to 1.063; *P* = 0.002), and in the adjusted analysis (ROR 1.040 per 1°C, 95% CI = 1.013 to 1.066, *P* = 0.002). Similar associations were found when using mean temperature over 13 days prior to the date of death (or equivalent control dates) (Appendix 4).

DISCUSSION

Summary

This analysis of routine medical records held over >300 general practices in England has confirmed that lower temperatures over 3- and 13-day periods were associated with increased risk of death in people aged ≥65 years. These effects were particularly marked for deaths occurring in the winter months, for the circulatory and respiratory causes typically associated with excess winter mortality. However, though this study found some evidence that patients living in northern parts of England and males were more vulnerable to cold weather, it was not possible to demonstrate changes in effects when comparing characteristics such as age, living situation and location, presence of chronic diseases, and average local housing energy efficiency.

Strengths and limitations

This was a large study, including 537 623 patients from 322 practices across England, which are considered broadly representative of all English practices.[15] More than 34 000 deaths were included, making this analysis particularly powerful for investigating interactions, compared with the authors' previous work.[4] The authors

Table 5. Unadjusted and adjusted interaction effects with average temperature fall per 1°C (3-days lag period)[a] on death among patients aged ≥65 years who died in winters of the financial years 2012/2013 to 2013/2014 due to diseases of the circulatory system, respiratory system, nervous system, or mental and behavioural disorders (*N* = 7710 deaths)

	Unadjusted				Adjusted		
	OR[b]	ROR[c]	95% CI	*P*-value	ROR	95% CI	*P*-value
Temperature* sex (ref=male)	1.090						
Female	1.070	0.982	0.962 to 1.003	0.091	0.980	0.959 to 1.002	0.082
Temperature*age died (ref=65–74), years	1.075						
75–84	1.079	1.004	0.969 to 1.041	0.820	1.006	0.971 to 1.044	0.729
≥85	1.079	1.004	0.972 to 1.038	0.795	1.012	0.978 to 1.048	0.488
Temperature*community (ref) or institution	1.080						
Institution	1.067	0.987	0.955 to 1.019	0.431	0.989	0.956 to 1.022	0.516
Temperature*urban (ref=urban conurbation)	1.096						
Cities and towns	1.068	0.975	0.951 to 0.998	0.036	0.984	0.959 to 1.010	0.227
Rural	1.088	0.993	0.956 to 1.031	0.700	0.989	0.950 to 1.030	0.592
Temperature*IMD (ref=Q1)	1.080						
Q2	1.092	1.011	0.979 to 1.045	0.493	1.012	0.979 to 1.046	0.488
Q3	1.074	0.994	0.962 to 1.028	0.740	0.997	0.964 to 1.030	0.820
Q4	1.066	0.987	0.953 to 1.021	0.448	0.988	0.953 to 1.024	0.497
Q5 (most deprived)	1.079	0.999	0.963 to 1.035	0.956	0.992	0.955 to 1.031	0.685
Temperature*house energy efficiency (ref=Q1)	1.069						
Q2	1.076	1.006	0.972 to 1.043	0.718	1.012	0.978 to 1.049	0.494
Q3	1.074	1.004	0.969 to 1.041	0.808	1.008	0.973 to 1.046	0.645
Q4	1.079	1.010	0.975 to 1.046	0.598	1.013	0.977 to 1.052	0.486
Q5 (highest inefficiency)	1.099	1.028	0.989 to 1.068	0.167	1.027	0.984 to 1.071	0.215
Temperature*emergency admission (ref=no)	1.093						
Yes	1.075	0.983	0.959 to 1.010	0.221	0.979	0.953 to 1.006	0.132
Temperature*chronic conditions[d] (ref=no)	1.079						
Yes	1.077	0.998	0.975 to 1.022	0.894	0.999	0.975 to 1.024	0.917
Temperature*north/south divide (ref=south)	1.067						
North	1.108	1.038	1.013 to 1.063	0.002	1.040	1.013 to 1.066	0.002

*[a]Based on temperatures of date of death and 3 days previous (case day), and 28th day before date of death and 3 days previous and 28th day after date of death and 3 days previous (control days). [b]Odds ratio per 1°C fall in temperature. [c]Relative odds ratio to indicate modifying effect of factor to temperature, for example, for sex: odds ratio for females divided by odds ratio for males: ROR female = 1.070/1.090 = 0.982. [d]Diagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. * = interaction. COPD = chronic obstructive pulmonary disease. OR = odds ratio. ref = reference. ROR = relative odds ratio.*

employed a case-crossover analysis, which is particularly powerful for investigating the effect of short-term exposures such as low temperature on discrete outcomes, and is free of confounding effects of between-person variables.[17,18] Any interactions detected however would not carry this advantage. The study used a wide range of covariates, including sociodemographic and geographic characteristics, clinical factors, and house energy efficiency characteristics, though marital status could not be included due to many missing data in CPRD. This study focused on recent winters of 2012/2013 and 2013/2014, but the winter 2013/2014 showed the lowest number of excess winter deaths since records began in 1950/1951,[27] making it harder to detect associations.

It is possible that reasons for winter deaths may lie outside purely medical explanations. In particular, improvements to housing through insulation or servicing of boilers, more suitable clothing or heating in cold weather, and property characteristics such as construction and age[28] may carry more influence. This study included a measure of energy efficiency in homes in the patient's LSOA — this however was of limited value because it could not be attributed to an individual patient's home condition. Furthermore, energy performance data only exist for properties when constructed, sold, or let, in particular those that have been on the property market since 2010; relevant data may therefore be particularly lacking for people aged >65, and explain the lack of association with temperature-related mortality in this study's analysis.

This study investigated differences in

relative risk between subgroups of patients, but in the absence of differences in relative risk, it is still likely that those individuals who are constantly at high risk (such as people aged >85 years) will show the greatest increase in *absolute* risk during periods of cold weather.

Comparison with existing literature

Some ecological studies in Great Britain investigated the relationship between excess winter mortality and deprivation, and found a weak or no association,[8–11] in line with this study's results. Aylin *et al* concluded from an ecological study that lack of central heating was significantly associated with dying in winter,[11] though Wilkinson *et al* found no association between difficulties in keeping the house warm and vulnerability to winter mortality in their cohort study,[7] in line with this current study's results using an average house energy efficiency measure. Furthermore, Wilkinson *et al* found little evidence for differences between regions, age groups, and markers for illness such as shortness of breath, depression, or taking more than five medications, but found some evidence of increased vulnerability for females and patients with pre-existing respiratory illness.[7] Similar to Wilkinson *et al* this current study's results showed no differences between age groups. However, this current study found some evidence of less impact of low temperature for females in winter for causes typically associated with excess winter mortality, but the authors did not find associations for patients with previous emergency admission(s) and patients with chronic conditions. Hajat *et al* observed little modification of the cold effect by sex in their ecological study, but did find that people in nursing and care homes were more vulnerable to both hot and cold weather.[8] The current study did not find an association between living in institutions and risk of death related to cold weather.

Implications for research and practice

The authors have not found evidence to support the use of existing data in medical records to identify those at increased risk of death during cold periods, leaving GPs without the necessary tools to implement NICE recommendations. Alternatively, GPs or general practices might identify vulnerable patients by communication with other medical staff to increase knowledge about patients, so-called team-based continuity of care, or by improving access and use of comprehensive information about a patient's previous healthcare encounters for providers caring for a patient, so-called informational continuity.

It has been demonstrated that, though individual days that are exceptionally cold carry the highest risk, such days are rare, and that the majority of deaths due to cold weather are attributable to moderate cold rather than severe cold.[2] If public health interventions or advice to patients are geared only to self-care on the coldest days, little impact will be made on the burden of excess winter mortality. Population- level interventions that focus on the effects of moderate cold are most likely to decrease burden in the population and the need for emergency medical care. Evaluative studies of innovations in building designs are required, at the same time that such innovations are occurring, or of retrospective improvements of older housing stock.

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Ethical approval

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The authors have declared no competing interests.

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Appendix 1. Identification of flu uptake from CPRD immunisation file

Winter influenza vaccination starts usually in September as suppliers start to deliver vaccines to GP practices from September onward.
The authors identified patients who had taken their flu vaccination in CPRD immunisation file by using the following medical codes: 6, 12336, 18330, 18684, 32942, 44555, 71122, 94301, 95092, 97941, 98183, 98184, 98203, 98217, 98234, 98302, 98303, 98304, 98306, 98449, 104688, 105077, 105195, 107413, 107573, 107730

CPRD = Clinical Practice Research Datalink.

Appendix 2. Causes of death according to ICD-10, version 2016 (N = 34 777)

	Winter (December–March) %	Spring and first part summer (April–July) %	Second part summer and autumn (August–November) %	Total *N*
Certain infectious and parasitic diseases	37.29	30.23	32.49	354
Neoplasms	33.78	32.82	33.4	9624
Diseases of the blood and blood-forming organs and certain disorders involving the immune mechanism	30.65	37.1	32.26	62
Endocrine, nutritional, and metabolic diseases	35.8	33.41	30.79	419
Mental and behavioural disorders	39.17	30.66	30.18	2913
Diseases of the nervous system	41.24	27.71	31.05	1501
Diseases of the eye and adnexa	0	50	50	2
Diseases of the ear and mastoid process	100	0	0	1
Diseases of the circulatory system	36.04	32.36	31.6	10203
Diseases of the respiratory system	41.22	30.12	28.66	5527
Diseases of the digestive system	35.34	34.16	30.5	1446
Diseases of the skin and subcutaneous tissue	32.06	29.77	38.17	131
Diseases of the musculoskeletal system and connective tissue	38.33	29.62	32.06	287
Diseases of the genitourinary system	34.98	33.2	31.82	729
Pregnancy, childbirth, and the puerperium	0	0	0	0
Certain conditions originating in the perinatal period	100	0	0	1
Congenital malformations, deformations, and chromosomal abnormalities	24	44	32	25
Symptoms, signs, and abnormal clinical and laboratory findings, not elsewhere classified	33.63	31.99	34.38	797
Injury, poisoning, and certain other consequences of external causes	0	100	0	1
External causes of morbidity and mortality	34.59	33.11	32.3	743
Factors influencing health status and contact with health services	0	0	0	0
Codes for special purposes	54.55	9.09	36.36	11
OVERALL	36.59	31.53	31.88	34 777

ICD-10 = International Classification of Diseases, 10th Revision.

Appendix 3. Unadjusted and adjusted interaction effects with average temperature fall per 1°C (13-days lag period)[a] on death among patients aged ≥65 years who died in the financial years 2012/2013 to 2013/2014 (*N* = 34 752 deaths)

	Unadjusted				Adjusted		
	OR[b]	ROR[c]	95% CI	*P*-value	ROR	95% CI	*P*-value
Temperature*sex (ref = male)	1.015						
Female	1.012	0.997	0.987 to 1.006	0.524	0.997	0.988 to 1.007	0.535
Temperature*age died (ref = 65–74), years	1.014						
75–84	1.013	0.999	0.986 to 1.013	0.944	1.000	0.986 to 1.014	0.970
≥85	1.013	0.999	0.986 to 1.013	0.910	1.000	0.986 to 1.014	0.944
Temperature*community (ref) or institution	1.014						
Institution	1.005	0.991	0.974 to 1.007	0.276	0.991	0.974 to 1.008	0.289
Temperature*urban (ref = urban conurbation)	1.013						
Cities and towns	1.013	1.000	0.989 to 1.010	0.947	1.003	0.991 to 1.014	0.623
Rural	1.015	1.001	0.984 to 1.018	0.901	1.003	0.985 to 1.021	0.712
Temperature*IMD (ref = Q1)	1.010						
Q2	1.015	1.005	0.991 to 1.019	0.488	1.005	0.990 to 1.019	0.528
Q3	1.014	1.004	0.989 to 1.019	0.612	1.003	0.989 to 1.018	0.654
Q4	1.013	1.003	0.988 to 1.018	0.677	1.003	0.987 to 1.018	0.724
Q5 (most deprived)	1.016	1.006	0.990 to 1.022	0.457	1.004	0.988 to 1.021	0.611
Temperature*house energy efficiency (ref = Q1)	1.012						
Q2	1.016	1.004	0.987 to 1.020	0.666	1.005	0.988 to 1.021	0.578
Q3	1.012	1.000	0.984 to 1.016	0.992	1.001	0.985 to 1.017	0.906
Q4	1.011	0.999	0.983 to 1.015	0.902	1.000	0.985 to 1.017	0.906
Q5 (highest inefficiency)	1.016	1.003	0.986 to 1.021	0.698	1.006	0.988 to 1.025	0.542
Temperature*emergency admission (ref = no)	1.015						
Yes	1.013	0.998	0.985 to 1.010	0.738	0.997	0.984 to 1.010	0.660
Temperature*chronic conditions[d] (ref = no)	1.015						
Yes	1.011	0.997	0.987 to 1.007	0.530	0.996	0.986 to 1.006	0.433
Temperature*north/south divide (ref = south)	1.010						
North	1.020	1.009	0.999 to 1.019	0.084	1.010	0.999 to 1.020	0.078

*[a]Based on temperatures of date of death and 13 days previous (case day), and 28th day before date of death and 13 days previous and 28th day after date of death and 13 days previous (control days). [b]Odds ratio per 1°C fall in temperature. [c]Relative odds ratio to indicate modifying effect of factor to temperature, for example, for sex: odds ratio for females divided by odds ratio for males: ROR female = 1.012/1.015 = 0.997. [d]Diagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. * = interaction. COPD = chronic obstructive pulmonary disease. OR = odds ratio. ref = reference. ROR = relative odds ratio.*

Appendix 4. Unadjusted and adjusted interaction effects with average temperature fall per 1°C (13-days lag period)[a] on death among patients aged ≥65 years who died in winters of the financial years 2012/2013 to 2013/2014 due to diseases of the circulatory system, respiratory system, nervous system, or mental and behavioural disorders (*N* = 7710 deaths)

	Unadjusted				Adjusted		
	OR[b]	ROR[c]	95% CI	*P*-value	ROR	95% CI	*P*-value
Temperature*sex (ref = male)	1.160						
Female	1.123	0.968	0.940 to 0.997	0.031	0.971	0.942 to 1.001	0.058
Temperature*age died (ref = 65–74)	1.150						
75–84	1.146	0.997	0.948 to 1.048	0.893	0.999	0.951 to 1.050	0.964
≥85	1.132	0.984	0.940 to 1.031	0.506	0.995	0.949 to 1.044	0.958
Temperature*community (ref) or institution	1.141						
Institution	1.121	0.982	0.939 to 1.028	0.445	0.992	0.947 to 1.040	0.728
Temperature*urban (ref = urban conurbation)	1.156						
Cities and towns	1.124	0.973	0.942 to 1.005	0.094	0.986	0.953 to 1.022	0.455
Rural	1.167	1.009	0.958 to 1.064	0.721	1.012	0.956 to 1.071	0.681
Temperature*IMD (ref = Q1)	1.140						
Q2	1.160	1.016	0.972 to 1.064	0.476	1.015	0.970 to 1.063	0.519
Q3	1.124	0.985	0.942 to 1.031	0.516	0.985	0.941 to 1.031	0.509
Q4	1.121	0.983	0.982 to 1.030	0.475	0.982	0.936 to 1.031	0.478
Q5 (most deprived)	1.148	1.007	0.958 to 1.057	0.804	0.995	0.944 to 1.048	0.855
Temperature*house energy efficiency (ref = Q1)	1.138						
Q2	1.144	1.005	0.958 to 1.055	0.835	1.015	0.966 to 1.066	0.557
Q3	1.117	0.982	0.935 to 1.031	0.462	0.987	0.940 to 1.037	0.615
Q4	1.139	1.001	0.953 to 1.050	0.975	1.005	0.956 to 1.058	0.837
Q5 (highest inefficiency)	1.162	1.021	0.968 to 1.076	0.445	1.018	0.962 to 1.080	0.530
Temperature*emergency admission (ref = no)	1.142						
Yes	1.137	0.996	0.961 to 1.033	0.833	0.992	0.956 to 1.029	0.667
Temperature*chronic conditions[d] (ref = no)	1.136						
Yes	1.143	1.006	0.974 to 1.040	0.717	1.002	0.970 to 1.036	0.910
Temperature*north/south divide (ref = south)	1.122						
North	1.177	1.049	1.015 to 1.083	0.004	1.048	1.013 to 1.086	0.007

*[a]Based on temperatures of date of death and 13 days previous (case day), and 28th day before date of death and 13 days previous and 28th day after date of death and 13 days previous (control days). [b]Odds ratio per 1°C fall in temperature. [c]Relative odds ratio to indicate modifying effect of factor to temperature, for example, for sex: odds ratio for females divided by odds ratio for males: ROR female = 1.123/1.160 = 0.968. [d]Diagnosed with one or more of the following seven chronic conditions: chronic renal disease, cancer, asthma, stroke, coronary heart disease, diabetes, or COPD. * = interaction. COPD = chronic obstructive pulmonary disease. OR = odds ratio. ref = reference. ROR = relative odds ratio.*